WETLANDS CREATION AND RESTORATION OF FUNCTIONAL VALUES AT A TITANIUM MINERAL OPERATION ALONG TRAIL RIDGE IN NORTHEAST FLORIDA

Jon A. Samborski[1] and Michael A. Miller[2]

AUTHORS: [1]Engineering Associate, E. I. DuPont De Nemours and Co., Inc., Starke, Florida 32091. [2]Senior Scientist, Environmental Services and Permitting, Inc., Gainesville, FL 32602

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Abstract. DuPont has been mining titanium minerals from a deposit along Trail Ridge in northeast Florida for approximately 40 years. The ridge extends into southeast Georgia and contains significant concentrations of titanium and other heavy minerals.

The creation of wetlands on lands impacted by mining is an essential part of DuPont's reclamation program. The restoration of important ecological functional values such as hydrology, water quality, soils, vegetation, macroinvertebrate and fish populations, and wildlife usage has been monitored on three created systems.

Comparison of these parameters with "natural" systems shows that the ecological values are being successfully restored. An overview of DuPont's mining operations and results from the wetlands restoration programs are presented.

INTRODUCTION

The creation of wetlands as mitigation for the disturbance or elimination of natural systems has been a concern among regulatory agencies, developers and conservation groups. Due to uncertainty associated with the return of the ecological functions in created wetland systems, regulators have required high replacement ratios and advance creation to offset temporary losses, or have denied permits. However, certain ecological parameters can be measured in the created systems and used to demonstrate that their ecological functions have been successfully restored. This information can then be used to support reasonable mitigation plans as has been done at DuPont's titanium mineral mine operating along Trail Ridge in northeast Florida. An overview of the mining process and review of three wetlands restoration projects are discussed.

OVERVIEW OF MINING OPERATIONS

Mining Site

DuPont has been mining for titanium minerals from an ore deposit in Northeast Florida for approximately 40 years. The deposit lies along a ridge, known as Trail Ridge, which extends from near Keystone Heights, Florida, on the south to near Jesup, Georgia, on the north. The ridge lies approximately 50 miles inland from the Atlantic Coast and closely parallels the present coastline of Florida and Georgia. The deposit is a beach sand deposit containing the titanium bearing minerals, ilmenite, leucoxene, and rutile, along with zircon and staurolite. These minerals generally comprise 2-3% by volume of the ore body with the balance being quartz, or sand. DuPont's titanium mineral products are used as feedstock for the manufacture of titanium dioxide pigment. Zircon products are sold for use in foundry, ceramic, and refractory applications. Staurolite products are sold for use as abrasive blasting media and cement manufacturing. Presently, DuPont has two active mine sites - the original Trail Ridge site located to the east of Starke, Florida, and the Maxville site which is located to the southwest of Maxville, Florida. The mining process consists of five main steps - Land Preparation, Dredging, Gravity Separation, Electrostatic and Magnetic Separation, and Reclamation.

Land Preparation

The current land use prior to mining is almost exclusively silviculture. Slash and longleaf pine plantations are managed by landowners for pulp, paper, pole and board applications. Timber stands are typically on a 20-year nominal rotation and coordinated with mining plans to maximize timber value. Wetlands cover approximately 6% of the land surface. In preparation for mining, timber is harvested by landowners using silviculture best management practices. Excess limbs, stumps and debris are raked into windrows, collected or burned. Just prior to dredging, approximately 1 foot of topsoil is removed and used in reclamation or as levees for water control.

Dredging

The water table in the mining area on Trail Ridge is typically 5-20 feet below the ground surface along the center of the ridge, and at or very near the surface on the flanks of the ridge. Therefore, a dredge is used to excavate the ore from a 15-20 acre pond. A rotating cutterhead digs at the face of the pond and loosens approximately 2000 tons per hour of ore at Maxville. A large centrifugal pump then captures the loosened ore and transfers it as a slurry through a floating pipeline at a rate of approximately 30,000 gallons per minute. The water in the dredge pond represents the natural water table. No water is added to create this pond. The water is recycled for use by the dredge and the gravity separation facility.

Gravity Separation

The ore slurry from the dredge is processed by a gravity separation facility called a wet mill. The wet mill floats in the same pond as the dredge, as shown in Figure 1. Since the valuable minerals are heavier than quartz, they can be separated from the lighter weight quartz with gravity concentrators called spirals. As the ore is fed to each spiral, gravity causes the heavier minerals to migrate to the inside of the spiral while the excess water washes the quartz to the outside. No chemicals are added to the spirals to effect this separation. Splitters at the bottom of each spiral then separate the minerals into a concentrate, middlings or tailings product. Four stages of spirals are used to maximize recovery and produce a final concentrate which contains approximately 85-90% valuable minerals. The final concentrate is stockpiled at the mine site and loaded into trucks for further processing.

The tailings are collected and pumped behind the wet mill to backfill the dredge pond. Since the valuable minerals only comprise 2-3% by volume of the ore, no pits occur as a result of mining. With the continuous placement of tailings behind the wet mill, the dredge pond remains approximately 15-20 acres in size and moves throughout the ore body as mining advances.

Electrostatic and Magnetic Separation

The final concentrate from the wet mill is washed with a caustic solution to remove organic coatings, then dried and fed to a dry mill where electrostatic and magnetic separators are used to produce distinct mineral products based on differences in their electrical and magnetic susceptibilities.

Reclamation

The reclamation process begins immediately after mining with the placement of tailings behind the wet mill. The tailings are graded to approximate pre-mine contours and topsoil is replaced. Natural grasses quickly stabilize the soil and supplemental grasses are established to prevent significant erosion. Pine seedlings are planted and silviculture operations are resumed in upland areas to produce mature pine forests.

Wetlands are created in areas where they generally existed prior to mining. Surface topography is graded to create shallow depressions to collect surface runoff. Elevations are often adjusted to allow groundwater to contribute to the hydrology of the wetland systems. Herbaceous and tree species suited for wetlands are planted within the standing water and transition zones surrounding the wetlands. DuPont replaces wetlands on an acre-for-acre basis.

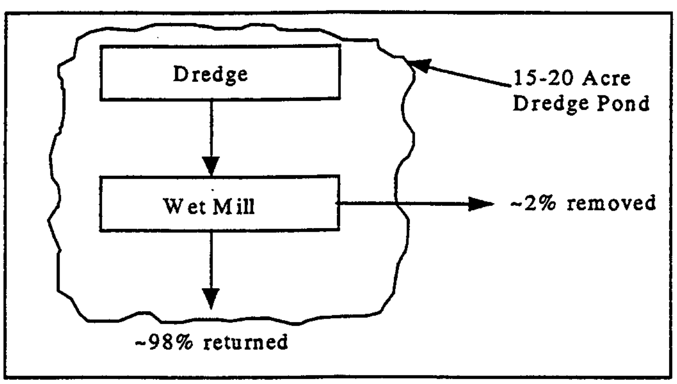

Figure 1 - Dredge and gravity separation facility.

ASSESSMENT OF FUNCTIONAL VALUES

There are almost as many classifications of wetland functions as there are wetland ecologists. One overview classification system, presented by Kundell and Woolf in *Georgia Wetlands - Trends and Policy Options* (1986), divides wetland values into environmental quality values, fish and wildlife values, and socioeconomic values. For this study we used a hierarchical system and categorized wetland functional values into ecosystem and population/community levels as shown in Table 1. This follows the typical "division of labor" in ecological research, and allows a simple grouping of commonly measured parameters. Three of our major wetland functional values (hydrology, vegetation, and soils) make up the Army Corps of Engineers' definition of a wetland. The general method we used was to measure these parameters in the created wetlands and compare them with "natural" systems where possible. These natural system controls were located in nearby timber areas on the Trail Ridge. Three distinct wetland systems were selected to document the successful creation and restoration of functional values.

The Highland North wetland is a small headwater wetland and associated small creek Being mined in 1979, this wetland was created prior to any regulatory requirement to do so. The headwater is a seasonal pond approximately 1 acre in size. It was created as a shallow depression to receive runoff from the surrounding upland pine plantation. The small stream developed on its own from a slightly improved natural drain and is braided in many places. Wetland trees, mainly cypress, were planted around the headwater area. Wetland vegetation, both woody and herbaceous, has volunteered in and around the streambed.

The Highland 1 wetland is a 3-4 acre isolated wetland created by grading a slight depression within the surrounding uplands to receive surface runoff and seepage from groundwater. As an isolated wetland, it has no apparent surface water drain although aerial photography indicates subterranean water movement to the east. This area was mined in 1982 and represents a more ambitious undertaking than the Highland North site. It included experimental plantings and an intensive monitoring program beginning in 1986, and upgraded in 1994. The site consists of a forested wetland fringe surrounding a deeper marsh area, typically two to three feet in depth.

The SR16 wetland is the most ambitious of the three projects. This area was mined in 1985. It was designed as a headwater, stream, floodplain system. A deeper depression was created for the headwater pond, followed by broad swales and improved channels for the marsh/stream complex.

Monitoring and Comparative Analysis

The monitoring network at each of the wetland sites consisted of a rain gage, water level recorder, staff gage, piezometers, photo stations, vegetation transects, fixed wildlife observations points, and sampling locations for macroinvertebrates, soil and surface water chemistry. Figure 2 shows the monitoring network for

Table 1 - Wetland Functional Values

Ecosystem Level	Population/ Community Level
Hydrology	Vegetation
Soils	Macroinvertebrates
Water Quality	Fish and Wildlife

the Highland 1 wetland. For the purpose of this paper, only the results from the Highland 1 system will be discussed.

Hydrology. Figure 3 shows the relationship between daily rainfall and the water elevation for the Highland 1 wetland. This system responds rapidly to rainfall events with typical increases of 0.5-1.0 feet in water level after a 1-2 inch rain event. However, the maximum variation observed during the sampling period Feb. 95 through Dec. 96 is only 1.6 feet. Also, the central marsh area did not go dry during the observation period although it has been reported to be dry during the 10 years it has been in existence. This suggests that the source of water for Highland 1 wetland is not only rainfall and runoff, but probably a significant groundwater component also. Important hydrologic functions which Highland 1 performs include water storage, flood control and groundwater recharge.

Water Quality. Table 2 shows water quality results for the Highland 1 wetland during the sampling period 1994-96 (in situ parameters were monitored monthly from November 1994 through December 1996, while laboratory parameters were analyzed for four quarterly samples from November 1994 to July 1995). No obvious trends existed when comparing the earlier data, from 1986-87, with the more recent data. Current results show a similarity to isolated wetland systems in North Florida, such as cypress domes studied by H. T. Odum and associates at the University of Florida's Center for Wetlands. pH is typically low, as are conductivity, dissolved solids and nutrients. Nitrogen is nearly all organic. One exception is organic carbon which is

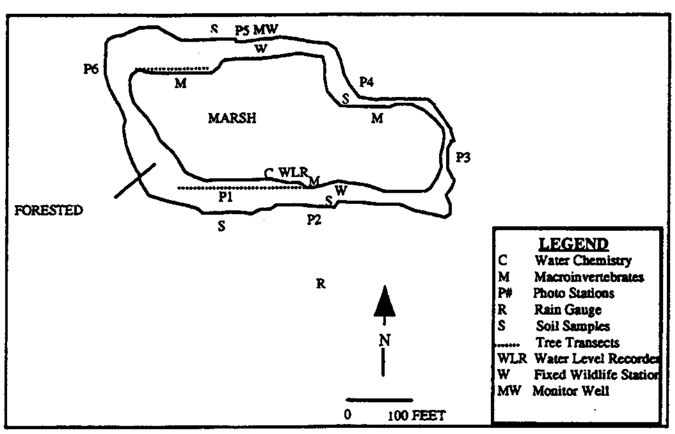

Figure 2 - Monitoring network for Highland 1 wetland.

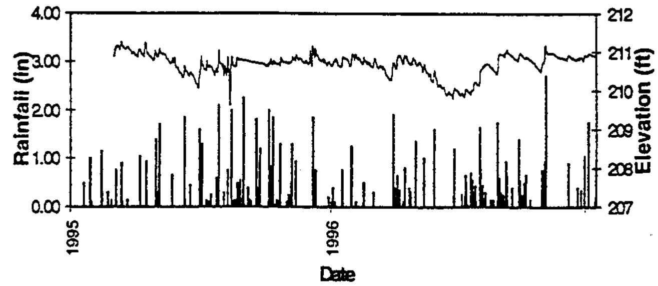

Figure 3 - Highland 1 daily rainfall and water elevation.

lower at Highland 1 (~12 mg/l) than more mature cypress domes (~40 mg/l). This would be expected to increase at Highland 1 as the water becomes more colored. The very narrow range of pH values at Highland 1 indicates the stability of this created wetland. The mean and standard deviation of pH at Highland 1 (4.51 ± 0.25) is extremely similar to that in a natural cypress dome in the study noted above (4.51 ± 0.36). The water quality results indicate a restoration of typical water chemistry functions similar to that of a natural system.

Vegetation. Tree monitoring at Highland 1 was conducted on fixed transects in the forested wetland fringe, and herbaceous monitoring was performed in the more open marsh area. Tables 3 and 4 show the results, respectively. Trees were originally planted in 22 experimental plots in 1986-87 to evaluate various species survival, growth, fertilizer treatments, and planting in less than ideal conditions. This information was used to select trees for planting in later projects. Survival of most species is excellent, even in the experimental plots with an overall survival of 70% during the period 1986-94. In the more representative transects, two year survival of ~10 year old trees was 100%. Comparison with a similar but unmined site, Maxville 1, indicates a high similarity index of 0.78. This is higher than the 0.60 value which has been required in otherforested reclamation projects in Florida. Tree density is also higher at Highland 1. Diversity is higher at the unmined site, which is not quite as cypress

Table 2 - Water Quality For Highland 1

Parameter	Mean	Range
pH (su)	4.51	4.09 - 4.96
Dissolved Oxygen (mg/l)	4.9	2.1 - 8.7
Conductivity @ 25°C (µmhos/cm)	36	28 - 48
Turbidity (NTU)	8.9	2.1 - 22.1
Total Suspended Solids (mg/l)	8.2	3.0 -16.0
Total Dissolved Solids (mg/l)	14	<5 - 29
Total Alkalinity (mg/l)	<0.4	<0.4 - 0.7
Total Organic Carbon (mg/l)	11.6	8.5 - 15.2
Total Kjeldahl Nitrogen (mg/l)	0.494	0.417 - 0.602
Nitrate and Nitrite (mg/l)	0.004	<0.001 - 0.007
Ammonia (mg/l)	0.014	0.001 - 0.038
Total Nitrogen (mg/l)	0.498	0.418 - 0.606
Total Phosphorous (mg/l)	0.023	0.008 - 0.046
Potassium (mg/l)	0.64	0.38 - 0.88

Table 3 - Highland 1 Tree Monitoring

Species	Experimental Plots Trees per acre	Experimental Plots Height (cm)	Representative Transects Trees per acre	Representative Transects Height (cm)
Red Maple	66	159	52	311
Pumpkin Ash	20	83	--	--
Dahoon Holly	--	--	4	105
Sweet Gum	94	257	--	--
Black Gum	316	97	100	164
Sweetbay	--	--	39	445
Slash Pine	--	--	9	363
Sycamore	4	128	--	--
Laurel Oak	110	176	--	--
Live Oak	97	179	--	--
Bald-cypress	395	126	1070	227

Survival in experimental plots (1986-1994) = 70%
Survival in representative transects (1994-1996) = 100%

	Trees per acre	Species	Diversity	Similarity
Maxville 1 - unmined	730	6	1.86	----
Representative transects - reclaimed	1274	6	0.92	0.78

dominated. Some of the herbaceous species present at Highland 1 were planted. However, most of the herbaceous cover is due to volunteer species. Comparison with the unmined site indicates extremely similar species number, percent cover and diversity index.

Macroinvertebrates. Macroinvertebrates were monitored at three locations. Timed qualitative samples were collected using sweep nets and other devices from a variety of appropriate habitats. Specimens were picked from these samples during a two man-hour period. Specimens were then returned to the lab for identification and enumeration by an expert entomologist. Table 5 shows the results from site 3 at the Highland 1 wetland. These results are typical of "natural" stream and wetland systems. The taxa richness falls in the 40th to 90th percentiles of results from streams in Florida, based on monitoring conducted by the Florida Department of Environmental Protection. The high diversity, large number of taxa, and presence of sensitive species like mayflies, are indications that the food chain functions associated with macroinvertebrate communities have been established at this wetland.

Table 4 - Highland 1 Herbaceous Monitoring - 1996

DOMINANT SPECIES

Xyris sp.	Yellow-eyed Grass
Juncus repens	Creeping Rush
Lachnanthes caroliniana	Red Root
Eleocharis sp.	Spikerush
Juncus sp.	Rush
Nymphaea odorata	White Water Lily

	Number of Species	Percent Cover	Diversity
Maxville 1 - unmined	29	136	3.63
Highland 1 - reclaimed	30	154	4.21

Table 5 - Highland 1 Macroinvertebrate Monitoring

Quarterly Sampling

	Number of Taxa	Diversity
November 1994	46	4.29
January 1995	25	3.42
April 1995	22	3.93
July 1995	31	4.69
January 1996	33	3.81
April 1996	39	4.78
July 1996	43	4.82
October 1996	51	4.83

Summary of October 1996 Sampling

Group	Number of Taxa	Group	Number of Taxa
Acarina	3	*Decopoda*	1
Coleoptera	7	*Odonata*	10
Diptera	17	*Oligochaeta*	3
Ephemeroptera	1	*Trichoptera*	1
Hemiptera	6	*Araneae*	1
Lepidoptera	1		

Fish and Wildlife. Fish monitoring was performed quarterly for one year during 1994-95 in the marsh and forested fringe at Highland 1. Sampling was conducted using a backpack shocker, with a one-hour electrofishing effort at each station. Pirate perch, banded topminnow, seminole killifish, and eastern mosquitofish were collected. This site supports consistent populations of these smaller fish. These are typical of small marsh/pond systems, and are another indication of the return of wetland functions, including the predominate role of fish in wetland food chains. Morning and evening wildlife surveys were conducted in the wetlands and surrounding uplands annually in 1995-96. Results are summarized in Table 6.

The wetlands are utilized by common water dependent and semi-water dependent species. Wood ducks, kingfishers, various frogs, and snakes indicate the use of different feeding guilds within these areas. Also using these areas are animals that frequent the transitional zones to feed and nest (white-tailed deer, turkey, quail, coyote, grey fox, and red winged blackbird). These species and uses are an indication of successful reclamation and use by common pine forest/wetland wildlife.

Soils. Soil sampling was conducted in the forested wetland and adjacent upland fringe. Mean values of results from the four stations sampled are given in Table 7. With the exception of iron, all constituents had low concentrations.

Table 6 - Fish and Wildlife Observed at Highland 1

Group	Number of Species
Mammals	10
Birds	37
Amphibians	3
Reptiles	5
Fish	4

Table 7 - Highland 1 Soil Sampling Results - 1994

Parameter	Mean Value
pH	5.0
Cation Exchange Capacity	1.7 meq/100 g
Organic Matter	0.74%
Phosphorus	10.0 mg/kg
Potassium	3.9 mg/kg
Magnesium	2.0 mg/kg
Calcium	19.0 mg/kg
Zinc	0.7 mg/kg
Iron	16.8 mg/kg

These analyses generally indicate relatively infertile soil. This is to be expected, considering the short amount of time the tailings had to regain their fertility, and the low original fertility of the pre-mining soils. Organic matter averaged 0.7%, which is near the 1% requirement imposed in Florida on a phosphate industry reclamation demonstration project. This level of organic matter, as well as the successful establishment of marsh and forest vegetation at Highland 1, indicates that, even with relatively infertile soils and no supplemental application of organic soils (mucking), a functional wetland system has developed.

CONCLUSIONS

Monitoring of key ecological parameters in created wetlands can be used to document the successful restoration of important functional values. At DuPont's titanium mineral mine on Trail Ridge in northeast Florida, three wetland systems have been monitored and indicate that the functions are similar to "natural" systems. The techniques used to create these wetlands should have application for future mining sites and as a basis for continuous improvement in wetlands restoration.

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